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Increase FCCU processing capacity with debottlenecking revamp

Fluid catalytic cracking units (FCCUs) are still the main units for modern refineries to obtain high-efficiency profits thanks to their low construction investment and ability to convert heavy oil into clean transportation fuels and high-grade petrochemical feedstocks.[1,2] Recently, maximizing the production of gasoline products with low olefin content and liquefied petroleum gas (LPG) with high propylene content[3] has become the main purpose for FCCUs. For many old units, technical modifications or new process packages are often adopted to overcome production bottlenecks to achieve the goal of changing production.

The FCCU at CNPC's Karamay Petrochemical Co. refinery in China was built in 1994 with a processing capacity of 0.5 MMtpy; a recent revamp in 2001 increased its capacity to 0.8 MMtpy. The reactor and regenerator scheme is shown in **FIG. 1.** In recent years, with the change of feedstock properties, higher processing capacity and different product yields favoring a lower diesel-to-gasoline ratio, this unit has been overloaded and operations have been unstable. For example, the particle separation efficiency of the riser termination separator was reduced due to serious wear at its inlet cylinder.

In April 2015, an unplanned unit shutdown was triggered due to serious catalyst loss. The standpipe to convey the regenerated catalyst to the riser had operated abnormally for some time, as the differential pressure across the slide valve was only 5 kPa–10 kPa. This indicates a potential safety hazard, as a high possibility exists for the oil-gas to enter the regenerator. The standpipe's unstable operation also caused large fluctuations in the reactor temperature, which consistently maintained a ± 3°C fluctuation. Due to a high recycle ratio of slurry and a low reactor temperature, the conversion ratio was low and the gasoline yield was only 42%, which failed to meet the company's gasoline blending requirements.

To produce clean gasoline that meets the China 6 gasoline standard and reduces the diesel-to-gasoline ratio, a series of advanced technologies were adopted to revamp the unit in August 2018. The main objective was to increase the unit's processing capacity to 1 MMtpy, eliminate existing bottlenecks, and achieve better product yields and higher profitability. The revamped unit has been restarted and operated continuously and smoothly for nearly 2 yr. The objective of this article is to describe the changes in the FCCU after the revamp.

TABLE 1. Detailed revamp contents

Reactor part	Regenerator part
Pressure adjustment	Pressure adjustment
Adding vortex breakers in the VSS outlet tube	Replacing with a new main air distributor
Replacing previous disc-donut stripping baffles with the new AF packings	Adding a ring-pipe distributor in the second-stage regenerator
Adding two-layer grating and downcomer grid above the stripping packings	Redesigning the regenerated catalyst standpipe and replacing with a new slide valve
Adding an steam distributor in the lower section of the stripper	Redesigning the recirculation catalyst standpipe and replacing with a new slide valve
Using a new Wye section for the riser	Replacing with a new spent catalyst slide valve

REVAMP FACETS

This revamp was only in the reactor-regenerator system of the FCCU. To minimize cost, the Karamay Petrochemical Co. wanted the licensor to retain major existing hardware, including the riser, vortex separation system (VSS), cyclones and main air blower, and to replace some other components. Detailed revamp contents are listed in **TABLE 1.**

Adjustment of pressure distribution. The pressure distribution of the reaction-regeneration system was adjusted to ensure sufficient solids separation efficiencies by the cyclones, although the processing capacity was increased by 25%. The comparison of the pressure distributions before and after the revamp can be seen in **FIG. 1. Note:** The pressure values in the squares and circles represent the pressure parameters at each point before revamp and after revamp, respectively, and the units of all the circled pressure values are denoted in kPa. The main change in pressure distributions lie in the reactor part, with a nearly 40-kPa increase.

Solution to fluidization problem. The operation of the inclined pipe conveying catalyst is a dense phase conveying process. A stratified flow between gas and solids is easily formed in the inclined pipe. Most bubbles flow along the upper part of the pipe, and not all gas fluidized solids produce static pres-

sure head, while the solids flow in the lower part of the pipeline. So, the pressure head established by the inclined pipe is much smaller than the vertical standpipe. The regenerated standpipe faced consistent problems of poor fluidization quality and fluctuating solids transportation, indicated by a low differential pressure across its slide valve. The layout of the regenerated catalyst standpipe was modified to improve the fluidization quality and increase its pressure drop. **FIG. 2** shows a comparison of its geometry and the layouts of aeration taps (C1–C11) before and after revamp. Before the revamp, the standpipe had two turning points and the catalyst was easy to bridge, which is not conducive to fluidization. The aeration gas was under a steam pressure of 0.6 MPa and a temperature of 260°C. The total flowrate was about 400 Nm^3/hr. After revamp, the standpipe became a long, straight pipe. The aeration gas was changed into nitrogen under a pressure of 1.4 MPa and a temperature of 30°C. Its total flowrate was increased to 650 Nm^3/hr, which is beneficial to improve the fluidization effect of catalyst.

Vortex breaker. The reactor cyclones have been in use for 17 yr. In 2015, it was determined that some cyclones' inlet cylinders were worn through, which was attributed to a strong gas vortex region cause by the upstream VSS.[4] The high-speed rotating catalyst particles in the VSS outlet tube and the cyclone inlet were the cause of wear. A vortex breaker was installed on the inner wall of the VSS outlet tube, as shown in **FIG. 3A.** Some plates are parallel to the gas flow direction, as shown in **FIG. 3B.** The aim is to weaken the swirling flow strength in the VSS outlet tube and, therefore, reduce the solids speeds into the downstream cyclones and the wear on the cyclone inlet walls.

AF stripper packing. Before the revamp, there were disc-donut baffles (**FIG. 4A**) in the spent catalyst stripper. To enhance stripping efficiency and reduce oil-gas entrainment into the regenerator, baffles were replaced by AF stripper packing, as shown in **FIG. 4B.** The AF packing is structured packing used in fluidized beds, as shown in **FIG. 4C.** It was installed in the stripper section to replace previous disc-donut baffles, as shown in **FIG. 4D.** In this revamp, 13 layers of AF packing were placed in the stripper section, and support beams were mounted on the stripper metal wall. Two ring-pipe stripping steam distributors were set below the packing section. Two layers of guide grating were also set above the packing section. Compared to the previous disc-donut baffles, the AF packing has smaller gas-solids contacting units and a high ratio of effective (filling) volume. The design of AF packing is to enhance bubble breaking and improve steam-catalyst contacting. The AF packing can also reduce solids back-mixing and improve solids residence time distribution. These two aspects are both beneficial to higher stripping efficiency.

Results and evaluation. After revamp, the processing capacity of the FCCU increased to 120 tph, corresponding to 1 MMtpy. The main operating parameters are compared in **TABLE 2.** In addition to increased processing capacity, several big changes occurred after revamp. The reaction temperature increased from 500°C to 525°C and temperatures in the two-stage regenerators both decreased by 15°C–20°C, which was the main contributor to raising the catalyst-to-oil ratio from 6 to 8 and one of the main methods for the significant increase in gasoline yield and conversion ratio. The increase in strip-

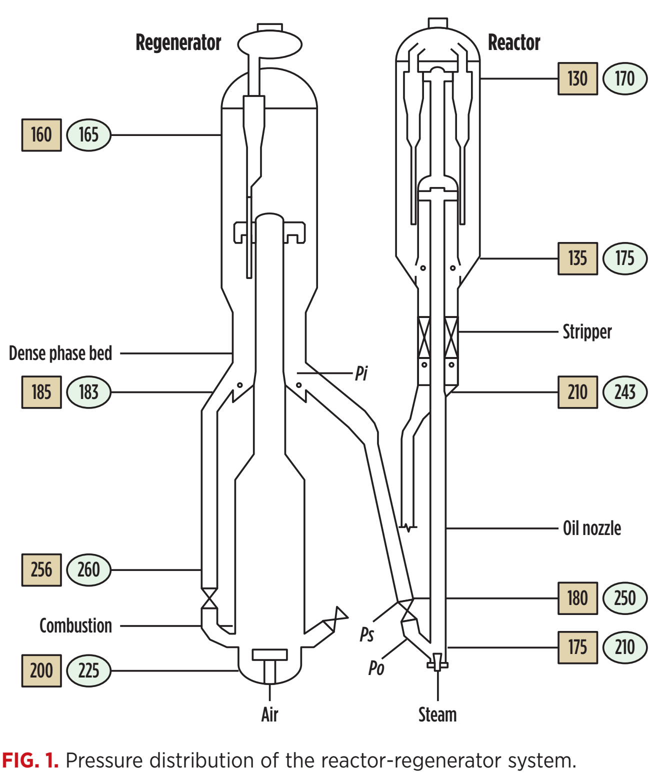

FIG. 1. Pressure distribution of the reactor-regenerator system.

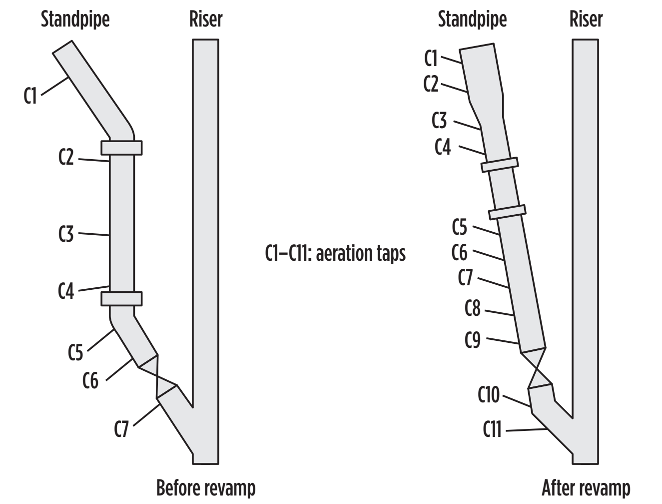

FIG. 2. Comparison of the standpipe geometry before and after revamp.

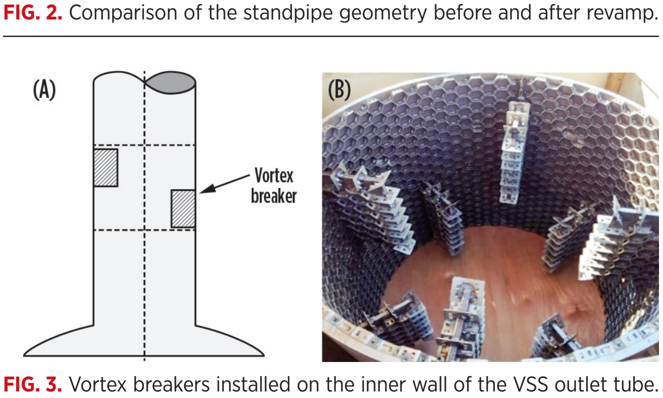

FIG. 3. Vortex breakers installed on the inner wall of the VSS outlet tube.

TABLE 2. Comparison of main operating parameters

Item	Before revamp	After revamp
Reaction pressure, kPa	130	170
Reaction temperature, °C	500	525
Top pressure in second regenerator, kPa	160	165
Temperature in second regenerator, °C	700	685
Fresh feedstock, tph	100	120
Preheat temperature of fresh feed, °C	270	250
Atomizing steam flowrate, tph	2.2	2.5
Main air flowrate, Nm^3/hr	80,000	80,000
Stripping density, kg/m^3	690	780
Stripping steam flowrate, tph	1.5	1.5
Stripping temperature, °C	490	515
First-stage regenerator temperature, °C	705	685
Density in the first-stage regenerator, kg/m^3	150	220
Catalyst-to-oil ratio (based on fresh feed)	6	8
Recycle oil, tph	45	9
Slurry oil, tph	30	5
Solid content in slurry oil, g/l	0.7	1

TABLE 3. Comparison of product yields

Product	Before revamp	After revamp	Change
Net gas, m%	1.16	1.36	0.2
LPG, m%	9.55	13.19	3.64
Gasoline, m%	42.75	50.39	7.64
Diesel, m%	39.14	29.06	–10.08
Coke, m%	4.59	4.72	0.13
Slurry, m%	2.56	1.04	–1.52
Loss, m%	0.25	0.24	–0.01
Conversion ratio, %	58.05	69.66	11.61
Light distillate yield, m%	81.89	79.45	–2.44
Total liquid yield, m%	91.44	92.64	1.2

TABLE 4. Comparison of catalyst properties before and after revamp

Item	Before revamp	After revamp
Carbon content in the spent catalyst, m%	0.98	1.09
Hydrogen content of the spent catalyst, m%	7.4	6.3
Carbon content in the regenerated catalyst, m%	0.08	0.1
Equilibrium catalyst activity, %	67	66

per density from 690 kg/m^3 to 780 kg/m^3 and the increase in combustion density from 150 kg/m^3 to 220 kg/m^3 provided much more residence time for stripping and combustion. The significantly decreased flowrates of the recycled oil and slurry indicate a higher one-way conversion rate.

The product yields are compared in **TABLE 3.** It can be seen that LPG and gasoline yields increased to 13.19% and 50.36%,

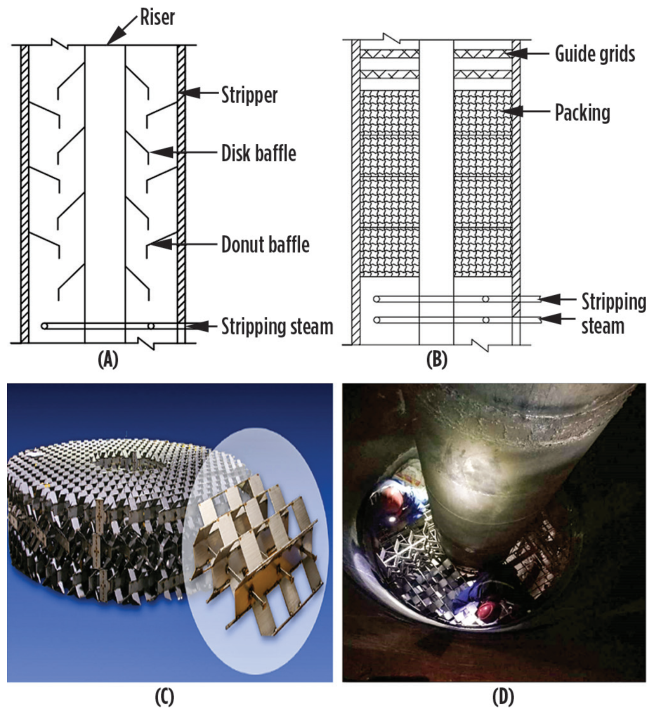

FIG. 4. Structure and installation of the AF packing.

respectively, which correspond to a 3.64% and 7.64% net increase for LPG and gasoline, respectively. LCO yields reduced to 29.06%, a 10.08% decrease from that before revamp. Total liquid yields and conversion increased to 92.64% and 69.66%, respectively. The net increases for both are 1.2% and 11.61%, respectively. Although the reaction temperature increased 25°C after revamp, dry gas yield was still low, with only a 0.2% increase. The hydrogen content in the coke of the spent catalyst was reduced from 7.4% before revamp to 6.3% after revamp (**TABLE 4**), which indicates an increase of stripping efficiency due to the installation of AF packing. The improved performance of stripper packing is also responsible for the decreased regenerator temperatures and the increased catalyst-oil ratio. The carbon content in the spent catalyst increased from 0.98% to 1.09% due to higher reaction temperature and conversion. However, the carbon content in the regenerated catalyst increased only slightly, which indicates the improvement of regenerator performance due to the new air distributor, successfully offsetting the increased coke burning capacity.

TABLE 5 compares the properties of gasoline and diesel before and after revamp. It can be seen that the final distillation point of gasoline increased from 179°C to 191°C with an increase in the top temperature of the main fractionating column. Although the olefin content was reduced by 12.3% due to the increase in heavy gasoline components, the octane number of gasoline still increased by 0.7% with the increased aromatic content. The diesel fraction range did not change much, but the diesel density increased to 918 kg/m^3 due to the addition of the aromatics content, which reduced the cetane number of diesel by approximately 7%.

The composition of LPG is presented in **TABLE 6,** where it can be seen that the propylene content in LPG was increased by approximately 17% (by volume), which resulted mainly from

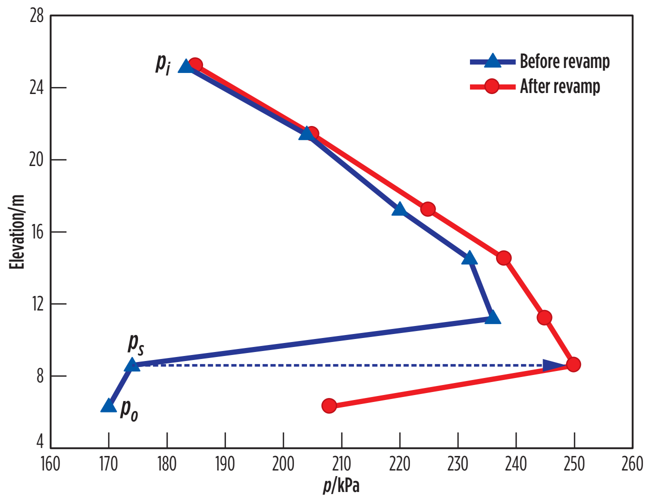

FIG. 5. Pressure profiles of the regenerated standpipe.

the high reaction temperature and the increased catalyst-to-oil ratio. The increased propylene yield can provide more feedstock for the downstream propylene polymerization unit.

Operation stability of the revamped FCCU. After revamp, the VSS and cyclone separators still maintained higher separation efficiencies at a higher processing capacity. This is indicated by the low solids content in slurry of 1 g/l, slightly higher than before revamp. The particulate concentrations in the inlets of the third-stage cyclone and the flue gas turbine could meet the requirements for long-cycle operation. The increased system pressure reduced the steam consumption by the steam turbine and the power consumption for the main air blower.

The fluidization performance of the revamped FCCU was improved with the redesigned regeneration standpipe. After revamp with the new operation condition, the reaction temperature fluctuation dropped from ±0.5°C to ±1°C, which was the best level of operating stability in the operating history of the unit. **FIG. 5** compares the pressure distributions in the regenerated catalyst standpipe before and after revamp. Note that p_i is the inlet pressure of the regenerated catalyst standpipe, p_S is the pressure before the slide valve and p_o is the pressure after the slide valve. After revamp, the apparent density in the standpipe was approximately 410 kg/m^3. The measured axial pressure distribution was consistent with the designed values. The pressure before the slide valve increased significantly, from 175 kPa to 250 kPa, as shown in **FIG. 5.** The pressure drop across the slide valve increased to 42 kPa, seven times that of the previous value.

The FCCU ran smoothly after revamp. The whole automation level of this unit was also improved considerably after revamp, which significantly improved the unit's safe operation performance. Due to the combination of new technologies used in this revamp, the revamped FCCU has achieved high gasoline yield and high conversion. As the main air blower and gas compressor were not changed, the investment cost was significantly reduced and a shortened construction period was realized. HP

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TABLE 5. Properties of gasoline and diesel products

	Gasoline		Diesel	
Item	Before revamp	After revamp	Before revamp	After revamp
Distillation, °C				
IBP	33.5	31	179	187.5
10%	52.5	49	204.5	207.5
50%	95.5	93.5	273	260.5
90%	168.5	165.5	353.5	354.5
FBP	179	191.5	370	372.5
Density, kg/m^3	719.5	722.5	881.7	918
Saturates content, %	30.5	40.1		
Aromatic content, %	11.5	16.6		
Olefin content, %	55.6	43.3		
RON	91.8	92.5		
CN			36.3	29.2

TABLE 6. Composition of LPG properties

Composition	Before revamp	After revamp
Propane,%	12.58	9.97
Propylene,%	30.57	47.02
n-Butane,%	8.42	4.06
Iso-butane,%	24.09	21.02
n-butene,%	3.76	2.79
Iso-butene,%	10.84	7.49
Trans-butene ,%	4.79	3.45
Cis-butene,%	4.84	3.51
Iso-pentane,%	0.11	0.1

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